Finite Element Modeling of Coastal Circulation

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LONG-TERM GOALS

To develop finite element procedures for nearshore and shelf-scale operations using unstructured grids which can be adapted in a real time data assimilative manner. Initial application is to the Yellow Sea, with technology transfer from parallel efforts in the Gulf of Maine.

OBJECTIVES

- Develop a realistic circulation model for the Yellow Sea. Processes must include tides and tidal rectification, wind, remote forcing, and baroclinic forcing.
- Develop and archive climatological circulation for the Yellow Sea, in 6 bimonthly seasons.
- Develop data-assimilative methods for shipboard limited-area nowcasting and forecasting using inverse methods and the above results as prior estimates.

APPROACH

The work is carried out in collaboration with Dr. Cheryl Ann Blain of NRL. The climatological circulation is computed using full-physics prognostic models. All calculations are fully 3D. Archived physical fields are web served both in raw data and graphical form.

New data-assimilation software and analytical approaches are tested first in the Gulf of Maine context, where the phenomena are well understood and data is relatively abundant; then in the Yellow Sea via Observational System Simulation Experiments. Beta versions of software are distributed within the Quoddy Users' Group for testing and refinement. Mature models and data products are transferred to NRL.

WORK COMPLETED

We have finalized our 3D climatological seasonal circulation study of the Yellow and Bohai Seas under combined dynamics resulting from baroclinic, wind, and tidal forcing, as well as mean river input from the Changjiang River (Naimie et al. (1999)).

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We have constructed a data-assimilative forecast modeling system (FCAST) for predicting the oceanic environment in real-time at sea. The modeling system involves three components: 1. an oceanic basin scale storm surge model (ADCIRC; Luettich et al (1992)) which is forced by atmospheric forecast products from the National Weather Service and provides the far-field response for the local data-assimilative model, 2. the nonlinear Dartmouth Circulation Model (QUODDY; Lynch et al (1996)) which predicts the local oceanic environment, and 3. a linear inverse model (TRUXTON; Lynch et al (1998)) which adjusts local tidal boundary conditions for QUODDY in order to minimize the discrepancy between QUODDY and current observations. A forecast calculation is accomplished by a single run of component 1., followed by the iterative solution of modeling components 2. and 3. until a convergence criterion is met.

We examined the capabilities of FCAST for shipboard application in the Gulf of Maine/Georges Bank region during a weeklong workshop in December of 1998 focused on a set of Observational System Simulation Experiments. FCAST was subsequently implemented at sea during four cruises to Georges Bank during the spring of 1999. In addition to the assimilation of shipboard ADCP data, shipboard hydrographic and atmospheric measurements were incorporated into the modeling system. The resulting forecast products were used by observationalists to facilitate their tracking of zooplankton and larval fish cohorts as well as dye released in the ocean.

We are completing development of an adjoint model for implementation in the forecast modeling system to invert wind-band signals from ADCP data (Lynch and Hannah (1999)).

We are currently conducting a set of Observational System Simulation Experiments with FCAST for the Yellow Sea, focusing on the Kyunggi Bay region for the local scale forecasts.

RESULTS

In Naimie et al (1999), we summarize our findings from our climatological seasonal circulation study of the Yellow and Bohai Seas. As discussed therein and also illustrated in Figures 1-3 of Lynch and Naimie (1998), the seasonal circulation displays distinct winter and summer circulation modes. The winter is dominated by wind-driven dynamics with southward flow along the Korean and Chinese coasts and a compensating return flow in the central Yellow Sea – the Yellow Sea Warm Current. In summer, the Yellow Sea Cold Water Pool, produced by winter cooling is isolated in the central Yellow Sea, setting up cyclonic circulation over the eastern Yellow Sea. Summer wind forcing, tidal rectification, and input from the Changjiang River are all important forcing mechanisms to the west of this cyclonic gyre.

The application FCAST in real-time at sea during four cruises to Georges Bank (for a total of 69 days at sea) proved to be an extremely valuable set of "computational experiments". Three-day forecasts of the oceanic environment were computed daily and delivered to the observationalists on board. The forecasts provided useful information to the scientific party, especially in the context of predicting the tidal response, which is the dominant forcing mechanism on Georges Bank. It should be emphasized that our research objectives during these cruises were to develop practical procedures, which can be implemented with today's technology, and to define the limits of such a forecasting system.

Observational System Simulation Experiments using FCAST for the Yellow Sea/Kyunggi Bay region (Figure 1) have yielded to some important findings. First, we have found that perfect inversion of linear tidal dynamics is achievable, even in the presence of noisy input data. Second, our studies indicate that nonlinear tidal dynamics can be inverted using FCAST and that the model can successfully forecast the tidal circulation in the entire bay (Figure 2), from the 3 day “numerical ship” ADCP record shown in Figure 1. Currently, we are examining the limitations of the modeling system in forecasting the climatological circulation during the winter and summer periods. Our preliminary studies indicate that the forecast skill under the combined forcing of baroclinic pressure gradients, wind, tides, and river input is more limited than for the more idealized cases discussed above.

IMPACT/APPLICATIONS

The combination of the Naimie et al. (1998) climatology, our OSSE studies in the Yellow Sea and Kyunggi Bay, and our experiences in applying our forecast modeling system on Georges Bank demonstrate the potential for a the application of this forecast system to coastal regions in the Yellow Sea as well as other coastal environments.

TRANSITIONS

Dr. Cheryl Ann Blain is an active participant on this project. All software developed is available to her and other Navy personnel via www html documents. The Quoddy Users Group is the vehicle for technical discussions and trial of the software in other applications, ensuring a robust conceptual development and software design. All methodological advances are prepared for publication in peer-reviewed.

RELATED PROJECTS

1 - USGLOBEC (NOAA/NSF): Georges Bank has been the training ground for most of the software development prior to this project. This application is still active and due to the large amount of data for this system, it remains a prime target for initial testing of nearly all project ideas.

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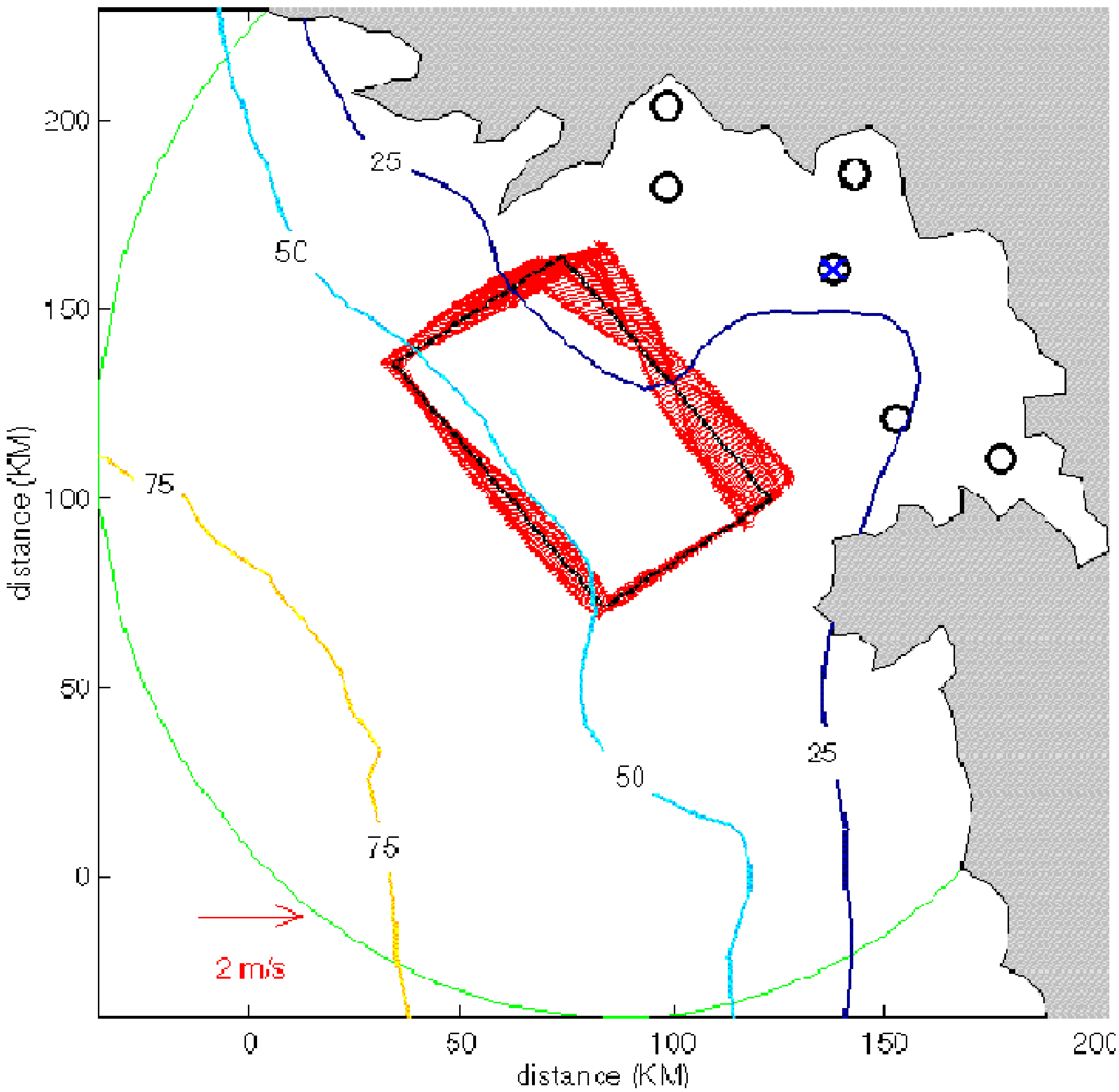
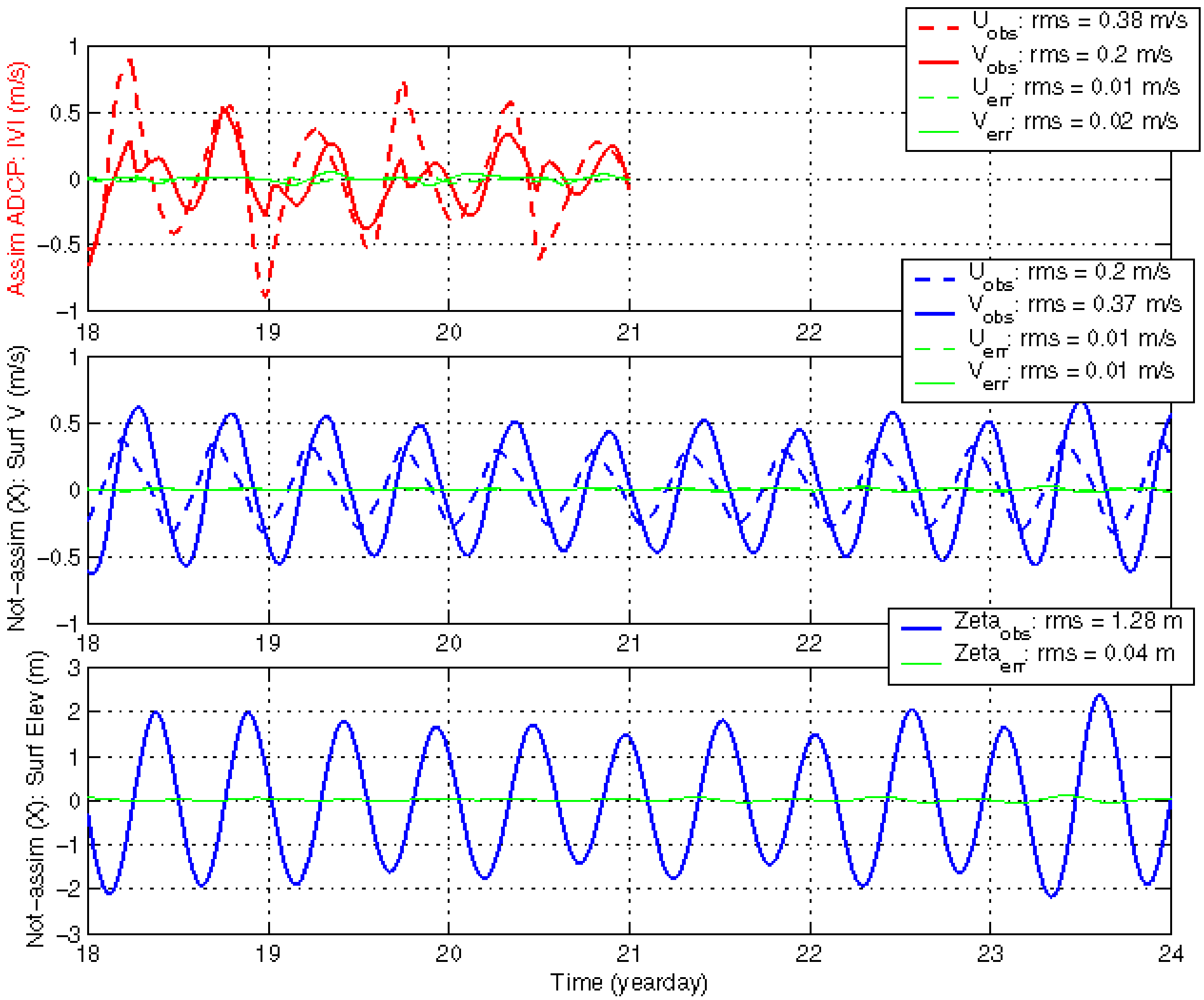


1. "Observational program" for nonlinear tidal simulation OSSE: The "numerical ship" steams around a rectangular box (black dots), making four circuits in a 3 day period and "measuring" the tidal velocity (red vectors) from an archived nonlinear numerical simulation. Numerical mooring measurements are made during the simulation for 6 locations within Kyunggi Bay (black circles), to provide measures of the ability of the forecasting system to extrapolate and forecast the dynamics inshore from the ship track. The area shaded in gray on the right side of the figure is the western coastal region of Korean Peninsula in the vicinity of Kyunggi Bay. The sweeping arc to the southwest is the boundary of the finite element mesh constructed for the study. This boundary separates Kyunggi Bay from the Yellow Sea. The 25, 50, and 75 meter depth contours are indicated for reference.



2. Forecast model results for the nonlinear tidal simulation OSSE. The top panel displays the time-series of the vertically-averaged ADCP "numerical ship" data assimilated (U_{obs},V_{obs}) and the unexplained errors (U_{err},V_{err}) associated with the forecast experiment. The middle and bottom panels indicate the success of the forecast results at the "numerical mooring" indicated by the blue "x" in Figure 1. As for the top panel, (U_{obs},V_{obs},$Zeta_{obs}$) indicate the "observations" and (U_{err},V_{err},$Zeta_{err}$) indicate the unexplained errors associated with the forecast experiment. Overall, FCAST is capable of reproducing the "observed" velocity (middle panel) and sea-surface elevation (bottom panel) to within 1.5 cm/sec and 4 cm respectively. Note that along with the successful extrapolation of the dynamics during the hindcast period (i.e. yeardays 18.0 to 21.0) the model is also successful at forecasting the hydrodynamic environment at the mooring (i.e. yeardays 21.0 to 24.0).